

KINEMATICS OF A LARGE-SCALE INTRAPLATE EXTENDING LITHOSPHERE: THE
BASIN-RANGE; Robert B. Smith, and Paul K. Eddington, Department of Geology
and Geophysics, University of Utah, Salt Lake City, Utah 84112-1183.

Upper lithospheric structure of the Cordilleran Basin-Range (B-R) is characterised by an E-W symmetry of velocity layering. The crust is 25 km thick on its eastern active margin, thickening to 30 km within the central portion and thinning to ~25 km on the west. Pn velocities of 7.8-7.9 km/s characterize the upper mantle while an unusual upper-mantle low-velocity cushion, 7.4 km/s-7.5 km/s, occurs at a depth of ~25 km in the eastern B-R and underlies the area of active extension. An upper-crustal low-velocity zone in the eastern B-R shows a marked P-wave velocity inversion of 7% at depths of 7-10 km also in the area of greatest extension. The seismic velocity models for this region of intraplate extension suggests major differences from that of normal, thermally undeformed continental lithosphere.

Interpretations of seismic reflection data, demonstrate the presence of extensive low-angle reflections in the upper-crust of the eastern B-R at depths from near-surface to 7-10 km.⁽¹⁾ These reflections have been interpreted to represent low-angle normal fault detachments or reactivated thrusts. Seismic profiles across steeply-dipping normal faults in unconsolidated sediments show reflections from both planar to downward flattening (listric) faults that in most cases do not penetrate the low-angle detachments. These faults are interpreted as late Cenozoic and cataclastic-mylonitic zones of shear displacement. Areas of extreme crustal extension (up to 100% or more) in the Sevier Desert are underlain by pervasive very low-angle faults that apparently accommodated most of the extension.

Most of the interior of the B-R has evidence of late-Cenozoic faulting, but current seismicity occurs at or near its boundaries. Major seismicity (with magnitudes of 7+) in central Nevada is associated with normal faults and components of strike-slip. Whereas primarily dip-slip earthquakes occur along the Intermountain seismic belt that marks the eastern B-R. These seismic zones mark the areas of principal strain-release within the extending western North American plate. Important seismicity parameters that characterize this region of extension are: (1) maximum focal depths that seldom exceed 15 km and mark the maximum depth of brittle deformation, (2) the maximum magnitudes of ~7.7, and (3) dominant down-slip extension.

The recent Ms7.3, 1983 Borah Peak, Idaho earthquake has provided important insights into the mechanical processes accompanying brittle extension. Detailed aftershock data from this large earthquake; the 1959, M7.5 Hebgen Lake, Montana; and the 1954, M7.1 Dixie Valley, Nevada earthquakes show the following important characteristics: (1) mainshock nucleation at mid-crustal depths of ~15 km; (2) nucleation along moderate, 45°-65° dipping planar fault zones; (3) aftershock distributions that are clearly above the depths of the mainshock; (4) for the Borah Peak earthquake, equal vertical and horizontal components of ~1 m slip corresponding to 10^{-5} down-dip strain; and (5) mainshock/aftershock distributions that extend laterally beyond the surface faulting. The geometry and style of crustal faulting inferred from these large magnitude intraplate events is a paradox compared to fault-plane orientations

inferred from the observed seismic reflection data and modal planes of smaller regional earthquakes -- the appearance of low-angle and listric faulting with Quaternary-Holocene displacement versus the through-going steeper-dip planar faults inferred from the large earthquakes.

Strain indicators (fault plane solutions, in situ stress, hydrofrac, etc.) indicate west to northwest extension along the western portion of the B-R but generally east-west extension along the eastern margin. Inversion of seismic moment tensors for the historical earthquake data suggest displacement rates of up to 7.5 mm/yr (10^{-17} s $^{-1}$ to 10^{-16} s $^{-1}$) in central Nevada but decreasing to very low rates ($<10^{-17}$ s $^{-1}$) across the aseismic zones of the central Great Basin. Toward the eastern margin of the Basin-Range displacement rates increase to 1.3 mm/yr (10^{-16} - 10^{-17} s $^{-1}$). The principal deformation is produced by the magnitude 6+ earthquakes. The contemporary deformation associated with historical seismicity compared with displacement rates inferred from Quaternary-slip are of the same order (mm/yr) -- implying a common driving mechanism since Late Cenozoic time. Vector solutions of intraplate motion⁽²⁾ and cumulative displacements from our seismicity data argue for 9 to 11 mm/yr east-west opening of the northern B-R. This conclusion suggests that the principal deformation is related to brittle release with smaller amounts of aseismic creep. Satellite measurements across the region are not yet well enough established to infer long-range rates.

Vertical deformation of the Great Basin is difficult to assess, but interpretations of re-leveelling (1920-1960), across the northern B-R, suggests a relative uplift, maximum in northern Nevada, at rates as large as 3 mm/yr. Relative downwarp on the east and west margins of the B-R are also the sites of large Pleistocene Lakes (Lahonton and Bonneville) that were influenced by the compliance of the lithosphere.

Rheological models (principally thermal and compositionally controlled) of the B-R lithosphere suggest a complex structure. The upper lithosphere appears to be composed of a 7-10 km brittle upper-crust -- the seismogenic layer. The intermediate and lower crust is modeled as interbedded brittle and plastic layers followed by a thin, brittle upper-mantle. The large magnitude earthquakes appear to nucleate at the base of the upper-crustal brittle zone near the peak of the shear stress maximum. The low-angle listric and planar faults extend throughout the upper and intermediate crust and only generally coincide with the theoretical brittle-ductile boundary.

These data and rheological properties provide input to a two-dimensional finite-element, visco-elastic modeling program (Lynch, 1984, personal comm.) that is used to interpret time and temperature dependent strain-rate models of lithospheric extension. Results of the computations will be discussed.

Lithospheric velocity models of the Yellowstone hotspot and its track the Snake River Plain (a youthful volcanic-tectonic area of active crustal extension within the northern Basin-Range) shows evidence of thermal perturbations of the lithosphere. At Yellowstone low-velocity upper-crust has been uplifted and extended by thermal expansion. Whereas subsidence associated with cooling produces significant topographic down-warp (~1 km) and rifting of the Snake River Plain. This model can be applied to an extending lithosphere if significant magmatic intrusion of the crust has accompanied extension.

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Mechanisms of B-R extension that have been suggested include: (1) lithospheric upwelling (mantle diapirism), (2) block tectonics, (3) a soft San Andreas transform fault, (4) ridge push from the Mid-Atlantic ridge, (5) buoyant uplift and concomitant extension, and (6) advection at the Basin-Range boundaries. None of the mechanisms can yet be clearly demonstrated. Although current data on velocity structure, strain rates, and rheological boundaries suggest a model of buoyant or vertically driven uplift with concomitant extension.

Important problems relative to intraplate lithospheric extension are: (1) The observation of low-angle listric and steep planar faulting in the same stress regime; (2) The role and importance of small earthquakes as indicators of sub-plate boundaries and their relationship to structure; (3) Thermal rheological factors controlling maximum focal depths and hence the thickness of the elastic lithosphere; (4) Can future large earthquakes nucleate on low-angle or listric faults? Is there evidence of multiple shocks associated with large earthquakes suggesting shallow-dip nucleation merging into flat detachments? What percentage of extension is accommodated by earthquakes? and (6) What is the distribution of brittle and ductile deformation in contemporary deformation? Together these data, models, and questions point out the problems of understanding continental lithospheric extension that should be addressed and compared on a global scale.

References

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